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RHEOLOGICAL STUDY OF SAE 5W30 ENGINE OIL AND THEIR EMULSIONS

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Abstract. *Lubricating oils are used in surfaces subjected to contact forces playing important role on the friction characteristics and heat transfer during the relative motion. One of the most important single property of lubricating oil is its viscosity because it is directly related to the energy loss due to molecules friction and stress developed in the bulk liquid or emulsions. Another important factor which may cause changes in oil quality is the amount of water present in the emulsion. The water can be present in two forms, either as free water (related to corrosion) or suspended in tiny droplets. In case of suspended water, the dispersed water droplet size affects the stability of oil-in-water emulsion. This paper presents an analysis of viscosity and shear stress in the lubricating oils and their emulsions. The viscosity results for pure oil and their emulsions were discussed and compared with the viscosity results of these fluids obtained in a program based on the Unit Cell Model. The analysis of the rheological properties of emulsions showed that the viscosity versus shear rate curves exhibited a Newtonian behavior, which demonstrating that no changes occurs in relation to the emulsions preparation, since it has the same characteristics of pure oil. It was also observed that a certain amount of water (30%) in emulsions decreases significantly the viscosity of the pure oil.*

Keywords: *Lubricating oils, Rheological properties, Viscosity, Unit Cell Model*

1. INTRODUCTION

Lubricating oils are widely used in many parts of industry in order to soften the wear of machines (Lopes and Carvalho, 2007). They are composed of basic compounds (saturated and aromatic hydrocarbons) and additives to impart desirable characteristics for use as lubricant. However, they are obtained from petroleum by refining processes, aiming remove undesirable aromatics and the minor portion of sulfur, nitrogen, and oxygen compounds (Freitas et al., 2003; Assumption Filho et al, 2003).

Bertolin and Scucato (2010) reported that lubricating oils perform a number of critical functions. These include to lubricate moving parts of engine, reducing friction, protecting, against wear, and removing contaminants from the engine, act as a cleaning agent, and act as an anticorrosive and cooling agent (Abro et al., 2013). Selection of lubricant is very important for providing machine tools a longer life (Vasishth et al., 2014).

According to Dantas et. al., (2004) the rheological behavior is an important factor in study of products. The rheology is a physical science of the viscosity, plasticity, elasticity and flow of matter, i.e., it constitutes a study of changes in form and flow of the material, embrace all such variants. The most important rheological parameter for lubricants is viscosity as it also affects the tribological properties like friction between interacting surfaces and wear (Vasishth et al., 2014). The viscosity determines the load carrying capability, as well as characteristics such as fluidity and heat flow, characteristics that must be maintained within predetermined limits (Carreteiro et al., 1989). According Rein (1978), the viscosity is essential in all aspects of lubrication, from this parameter, we obtain good operation of hydraulic systems, automatic transmissions and shock absorbers. The relationship between the viscosity and temperature is also important in lubricant rheology as well as for the life of machine elements (Barus, 1893).

During the obtaining or performance of lubricating oil occurs a rapid production of water and oil in emulsified form. The emulsions are composed of two immiscible liquid phases (oil and water). In this blend, one of the liquids (the dispersed phase) is in the form of globules within the other liquid (continuous phase), forming a stable blend. Emulsions are thermodynamically unstable and, thus do not form spontaneously, requiring supply power to form them by stirring or homogenizing. Over time, emulsions tend to return to steady state of oil separated from the water.

The rheological behavior of lubricating oils appears frequently as object of study in literature. Mawatari et al. (2013) studied the high pressure rheology of vegetable oils and determined equations for their viscosities as a function of the pressure and temperature. Santos et al. (2007) analyzed the thermal degradation process of mineral base lubricating oils by means of thermal, spectroscopic and rheologic analysis. Sánchez et al. (2011) determined the rheology of oleogels based on sorbitan and glyceryl monostearates and vegetable oils for lubricating applications. Mia and Ohno (2010) studied the relation between low temperature fluidity and sound velocity of lubricating oil.

In order to improve knowledge of the characteristics and behavior of oils and emulsions, this research intends to analyze the behavior of viscosity in pure 5W30 oil, and the effect of the variation of these characteristics caused by the effect of the volume fraction of water in the formation of the emulsions.

2. MATERIAL AND METHODS

2.1 Material

Studies have been carried out utilizing the lubricating oil SAE 5W30 produced by Brazilian industry. The characteristics of this lubricating oil are summarized in Tab. 1.

Table 1. Information of lubricating oil SAE 5W30. Source: Product Information.

Density at 20/ 4 ºC, kg/m^3	840
Kinematic viscosity at 40 ºC, mm^2/s	45,5
Kinematic viscosity at 100 ºC, mm^2/s	8,0
Viscosity Index	149
Flash point, ºC (VAC)	194
Pour point, ºC	-40
Mileage, Km	5000
Molecular Weight, g/mol	20000

2.2 Methods

2.2.1 Preparation of emulsions

The emulsions of the type W/O were prepared from the synthetic lubricant SAE 5W30. For the preparation of emulsions, water and oil were subjected to stirring in a homogenizer (Gehaka, T10 Ultra-Turrax, Brazil) for a period of 3 minutes with a speed rotation of approximately 9500 rpm and 21000 rpm. During this process the water was added slowly into the oil to avoid that phase separation occurred after the emulsion was ready.

2.2.2 Analysis of rheological behavior of emulsions

The rheological behaviors of emulsions were determined by tests performed with rotational rheometer Haake Rheostress 600 rheometer (Haake, Karlsruhe, Germany), coupled to a cylindrical sensor Z20 Din (Cylinder Ø 20 mm, ISO 3219). Data were visualized at the HAAKE RheoWin® software (version 4.41.0000). In the experiments, the samples volume used in the rheometer were 8 mL. The time and rotational speed of the sensor have been previously established on the order of 300 seconds and from 10 to 500 rpm, respectively.

2.2.3 Viscosities simulation

In order to predict the apparent viscosities versus temperature were made computational simulations utilizing a program developed with laboratory and data literature data by FORTRAN 90 software (Diniz e Castro, 2008; Oliveira et al., 2011).

The calculations for the program development are based on the unit cell model (UCM). The UCM provides numerical curves fitted to the experimental data characterizing the fluids analyzed in order to find the model that best fit the experimental study (Mixture Model and Vand Model).

The UCM considers the increase of the value of the thermal conductivity of the droplet, be due, mainly, to the micro-convection heat transfer, motivated by the Brownian movement of the droplet. In UCM, the droplets are considered as spherical, mono-dispersed and without clustering with homogeneous distribution in the base fluid (oil 5w-30). The UCM is one-dimensional, where the thermal conductivity of droplet is estimated by the combination of the mechanisms of conduction heat transfer in the droplet, micro-convection in the interface base fluid/droplet region due to the droplets Brownian movement and conduction in the remaining of the base fluid. Figure 1 illustrates the concept of the unit cell which serves as the basis for the development of the model.

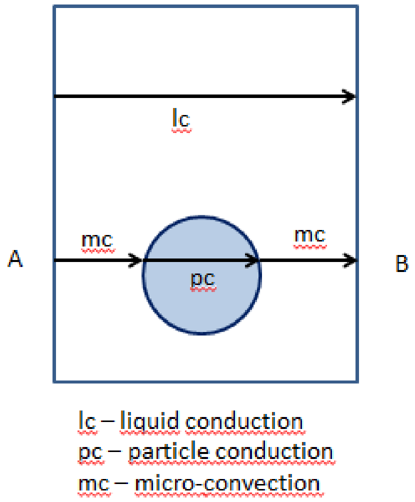


Figure 1 - Definition of unitary cell (Diniz and Castro, 2008)

Equation (1) defines the Unit Cell Method (UCM) of Hrishikesh et al. to calculate the increment of the thermal conductivity of the fluid in relation to the corresponding base fluid:

$$\frac{k_{eff}}{k_m} = 1 + \frac{k_p}{k_m}\eta\tau \tag{1}$$

where k_{eff} is the thermal conductivity of the fluid, k_m is the thermal conductivity of the base fluid, k_p is the thermal conductivity of the droplet, η is the dynamic viscosity and τ is the shear stress.

In this study, for the calculation of the dynamic viscosities of the synthetic lubricating oil 5W30 and their emulsions versus temperature, the UCM was incremented applying the Vogel model (Eq. 2).

$$\eta = A\,\exp\left(\frac{B}{C+T}\right) \tag{2}$$

where, A, B and C are parameters which depend on the type of fluid and T is the temperature of the system.

The thermal conductivity of the fluid was calculated using the method of Lakshimi e Prasad, presented in Eq. 3.

$$k_m = 0.0655 - 0.00005T + \frac{1.3855 - 0.00197T}{\sqrt{W_m}} \tag{3}$$

where W_m is the molecular weight.

2.2.4 Microscopy of emulsions

The emulsions of W/O were viewed through the optical microscope Nikon Eclipse LV 150 (Japan). Photos were taken Increased in 20 times across all the analyzed region. For the measuring of the droplet size existing in the emulsions, were used images obtained at an optical microscope and used in the free software ImageJ. The ImageJ is a free software for processing and images analysis, developed by Wayne Rasband at the National Institute of Mental Health, USA, in Java.

3. RESULTS AND DISCUSSION

The W/O emulsions were prepared composed of 30% of water and 70% of lubricant oil 5W30 and their rheological behavior was investigated. Figures 2 and 3 represent the results of the viscosity, shear rate and shear stress for W/O emulsions in a rotation of 9500 rpm and 21000 rpm, respectively. It is possible observe that the shear stress of the fluid is directly proportional to the velocity gradient. It can also be noted that the viscosity decreases when the applied shear rate increases until it reaches a limit. As can be seen in the Fig. 2 and 3, the lubricants presented linear curve of shear rate versus shear stress, indicating Newtonian behavior. Azevedo et al. (2005), Vasconcelos et al. (2010) and Vasishth et al. (2014) studied the rheological properties of mineral and synthetic oils and also observed that those oils showed Newtonian behavior.

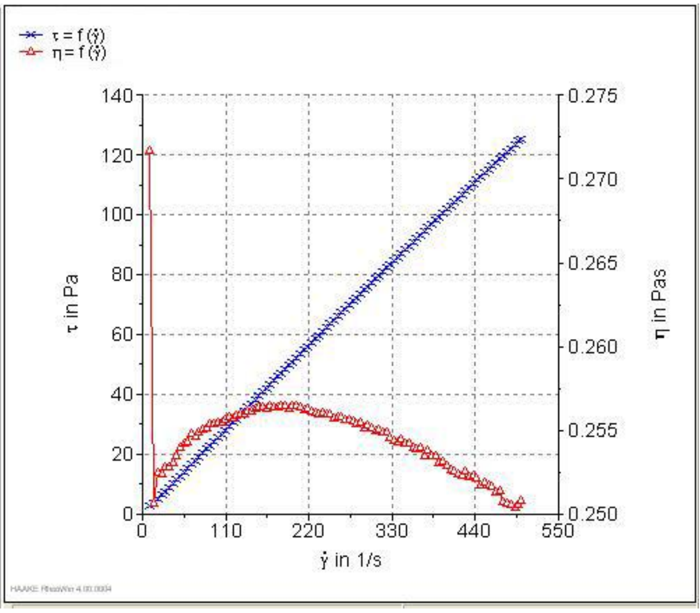


Figure 2. Shear stress x shear rate x viscosity of W/O emulsion stirred at 9500 rpm

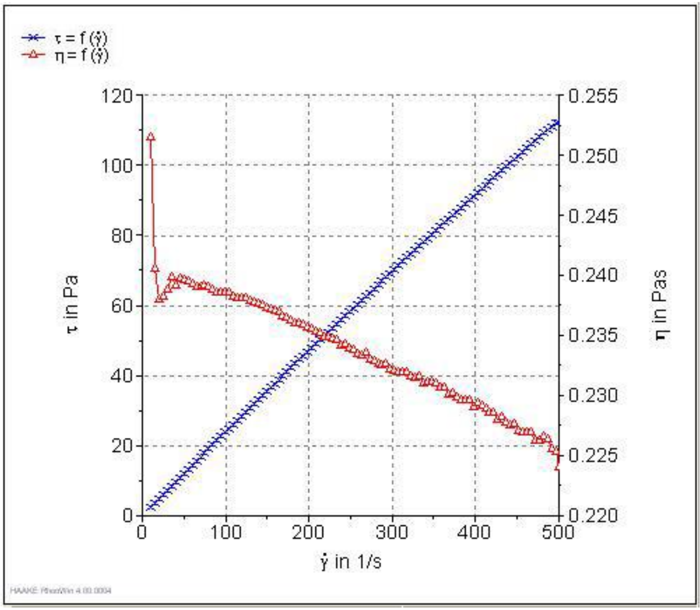


Figure 3. Shear stress x shear rate x viscosity of W/O emulsion stirred at 21000 rpm

The graph of the viscosity behavior versus volume fraction of W/O emulsion provided by the proposed numerical model is shown in the Fig. 4. The illustrated point represents the experimental results obtained for the W/O emulsion. Analysis of the graph was performed using a droplet of 100 microns diameter. The experimental point lies on the curve of Vand Model indicating that this model was the one that best fitted to the emulsion behavior.

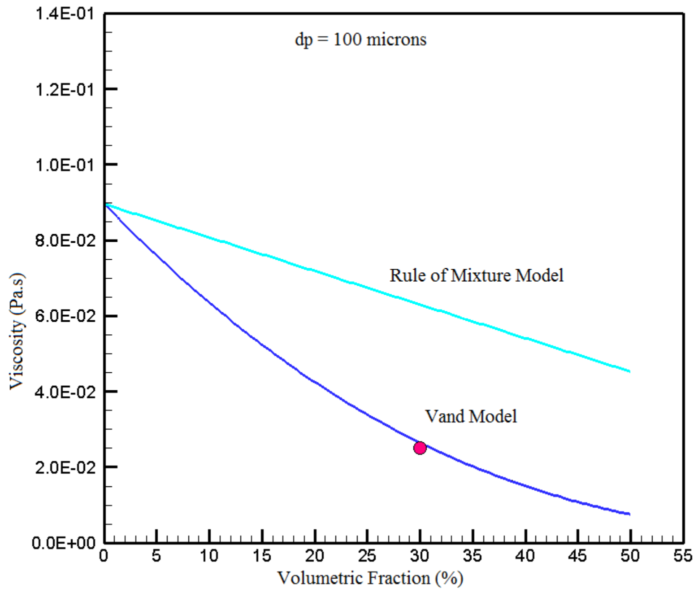


Figure 4. Viscosity x volumetric fraction of the emulsion with 30% water in oil

The graph of viscosity behavior with respect to temperature variation was also predicted by the proposed model and can be seen in Fig.5. This graph demonstrates the viscosities of the pure oil (5W30), of the water and of the emulsion for different temperatures. These values were taken from literature, being one point produced in the laboratory.

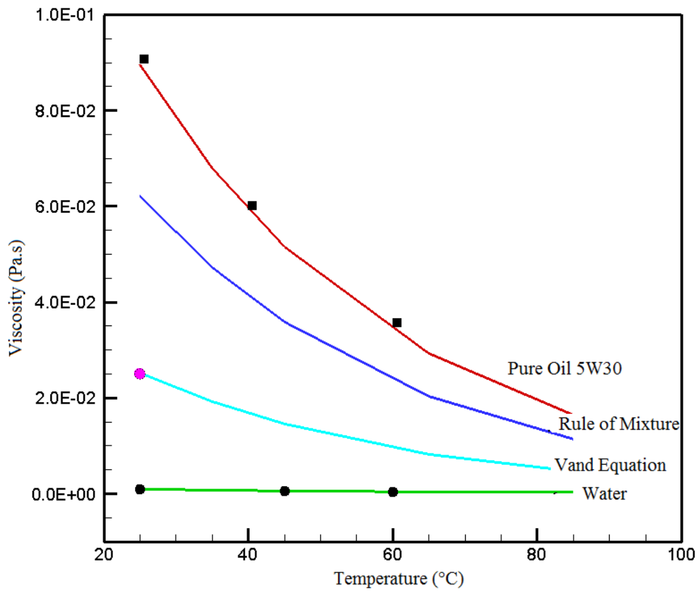
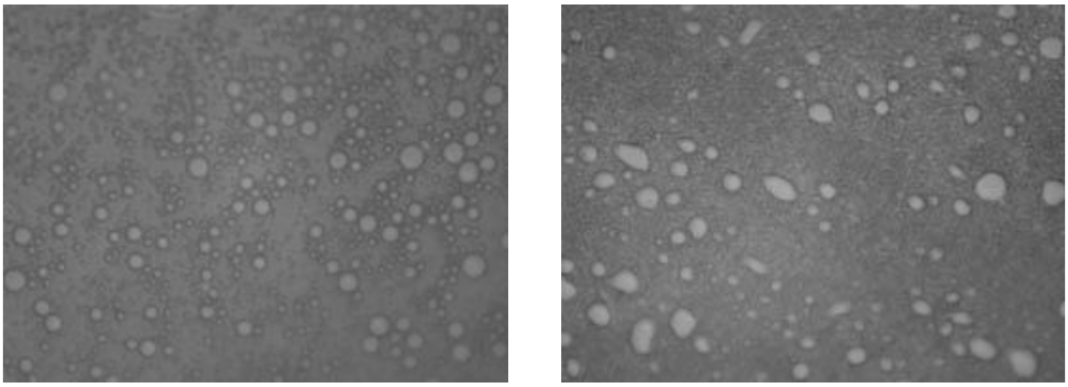


Figure 5. Viscosity x Temperature of the fluids

The experimental point produced for the emulsion also rebate on the curve of Vand Model as seen in Fig. (5). The other points, representing the viscosity of the oil 5W30 and of the water to different temperatures, are in good agreement with the numerical curves predicted by the model. It can be said that the model based on the Vand equation was once again the most suitable to represent the behavior of the W/O emulsion of a synthetic lubricating oil 5W30.

Figures 6a and 6b represent the emulsions formed by agitation at 9500 rpm and 21000 rpm, respectively. These figures were analyzed by optical microscopy with a 20-fold increase. In the emulsions, the phase composed of small droplets is known as dispersed or discontinuous phase, in this case is the water, and the suspending liquid is known as the dispersant or continuous phase, in the specific case is the synthetic lubricating oil 5W30.



(a) (b)

Figure 6- Emulsion formed by agitation at 9500 rpm (a) and at 21000 rpm (b) - Images made by optical microscopy with a 20-fold increase

The images show a significant variation of the size, shape, distribution and amount of droplets formed. It can be noted that with a higher rotation speed, the emulsion formed presents a smaller amount of larger droplets, these being well spaced droplets. It is also noted that in a greater rotation occurs the formation of a more homogeneous emulsion presenting a tendency to coalescence lower than the emulsion with greater distribution of droplets.

4. CONCLUSIONS

This paper presents an analysis of viscosity and shear stress in the lubricating oils and their emulsions. The water in oil emulsions (W/O) were prepared containing a ratio of 30% water in oil, stirred at 9500 rpm and 21000 rpm. The pure oil characteristics demonstrate a Newtonian behavior presenting a linear relationship between shear rate and shear stress. Regarding the rheological characteristics of the emulsions, it is possible to describe that both also exhibit a Newtonian behavior, which shows that no change occurs in relation to the preparation of emulsions, since it has the same characteristics of pure oil. In contrast, the dynamic viscosities show a small variation in relation to the preparation of emulsions. The emulsion with smaller droplet sizes, more stable, formed by a higher agitation (21000 rpm) exhibited lower viscosity than the one that present a wider distribution with larger diameters of droplets formed by a lower agitation (9500 rpm). So, it can be said that the ratio between the dynamic viscosities of the droplets and the pure base liquid increases as the droplet diameter is decreased. Moreover, it was also observed that a certain amount of water (30%) in emulsions decreases significantly the viscosity of the pure oil. The Numerical Model proposed in this paper provides the behavior of viscosity with respect to temperature variation in the emulsion. For such prediction, two equations were coupled to the UCM Model, the Mixture Model and the Vand Model, in order to select the best-fit model to the experimental study. The best-fit method to the experimental results of the emulsion and to the values taken from the literature for the pure oil and for the water was the Vand Model. These results were satisfactory due to their consistency with the literature. Owing to their sufficiently wide regions of applicability, the correlations developed represents a useful engineering tool for analysis and design applications.

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